RADIATION-EMITTING THIN-FILM SEMICONDUCTOR COMPONENT BASED ON GAN

The present invention relates to radiation-emitting thin-film semiconductor components based on GaN according to the preamble of patent claim 1 and according to the preamble of patent claim 18.

Conventional radiation-emitting semiconductor components often have a rectangular shape for reasons of production technology. The semiconductor components generally comprise a multilayer structure with an active, radiation-generating layer, said multilayer structure being deposited epitaxially on a carrier substrate. The carrier substrate is preferably electrically conductive in order to enable a vertical current flow. Moreover, it is expedient in many cases if the carrier substrate is transparent to the radiation generated in the active layer of the multi-layer structure. However, a high transparency is often at odds with a high electrical conductivity of the material for the carrier substrate. Thus, by way of example, sapphire used for GaN-based light-emitting diodes is transparent to blue light but is not electrically conductive. By contrast, although silicon carbide as carrier substrate for GaN light-emitting diodes is conductive and transparent, the transparency decreases as the conductivity increases, with the result that the properties of the semiconductor component are not ideal in this case either.

Therefore, one possibility for reducing the absorption losses and thus for increasing the external efficiency is the removal of the carrier substrate in conjunction with suitable mirror layers (thin-film concept). However, a semiconductor thin film is essentially a co-planar plate whose coupling-out efficiency is not

increased compared with a standard diode on account of the geometry. Particularly if a carrier substrate exhibiting only little absorption (for example GaN on SiC) has already been used for the semiconductor component, the increase in the external efficiency of the thin-film semiconductor component is too small to justify the increased technical effort for removing the carrier substrate.

In order to elucidate the problem area of coupling out radiation, figure 8 schematically shows a semiconductor component with the cones of coupling out radiation. Radiation can be coupled out of the semiconductor component only from a cone with an aperture angle of $\theta = \sin^{-1} (\pi_{ext}/\pi_{int})$, where π_{int} denotes the refractive index of the semiconductor material and π_{ext} denotes the refractive index of the surroundings. For a GaN semiconductor ($\pi_{int} = 2.5$), the coupling-out angle θ is 23° with respect to air ($\pi_{ext} = 1$) and 37° with respect to a plastic encapsulation ($\pi_{ext} = 1.5$). Radiation that is generated in the semiconductor component and does not impinge on the interfaces within a cone is finally reabsorbed and converted into heat. Although the coupling-out cone is large for GaN systems in comparison with GaAs systems ($\pi_{int} = 3.5$), it nevertheless leads to undesirably high radiation losses.

These conditions also do not change significantly with altered layer thicknesses. However, the thin-film geometry is expedient for the beam coupled out via the top side since the absorption is low on account of the short path in the semiconductor; for the beam coupled out laterally, by contrast, the efficiency may even be lower on account of the multiple reflections in the semiconductor.

Therefore, there are already various approaches for increasing the external efficiency of semiconductor

components through altered geometries. Mention shall be made here, in particular, of a so-called micro-patterning of the entire multilayer structure, which leads to an intensified lateral coupling out of radiation on account of the larger total area of the side areas of the multilayer structure. In addition, the side areas of the individual multilayer structures thus produced may be beveled. Examples of such semi-conductor components are disclosed in DE-A-198 07 758, EP-A-0 905 797 or JP-A-08-288543.

A further possibility for increasing the coupling out of radiation is shown in figures 3 and 5 of DE-A-199 11 717. Here, the multilayer structure with the active, radiation-generating layer is assigned individual radiation coupling-out elements in the form of sphere segments or truncated cones formed for example by means of corresponding etching of grown layers.

However, none of the documents cited with respect to the prior art deals with GaN-based thin-film semi-conductor components. GaN-based semiconductor components predominantly serve for generating radiation in the blue-green spectral range and have a plurality of layers comprising a GaN-based material. In the context of this invention, a GaN-based material is understood to mean not only GaN itself but also materials derived from GaN or related to GaN and also ternary or quaternary mixed crystals based thereon. What are included in particular in this respect are the materials GaN, AlN, InN, $Al_{1-x}Ga_xN$, $In_{1-x}Ga_xN$, $In_{1-x}Al_xN$ and $Al_{1-x-y}In_xGa_yN$ where $0 < x < 1$, $0 < y < 1$ and $x + y \leq 1$.

The present invention is based on the object of providing a radiation-emitting thin-film semiconductor component based on GaN which has an improved external efficiency of coupling out radiation.

In accordance with a first aspect of the present invention, this object is achieved by means of a semiconductor component having the features of patent claim 1. Advantageous refinements and developments of this semiconductor component are specified in the dependent claims 2 to 17.

The radiation-emitting thin-film semiconductor component according to the invention has a multilayer structure based on GaN, which contains an active, radiation-generating layer and has a first main area and a second main area - remote from the first main area - for coupling out the radiation generated in the active, radiation-generating layer. Furthermore, the first main area of the multilayer structure is coupled to a reflective layer or interface, and the region of the multilayer structure that adjoins the second main area of the multilayer structure is patterned one- or two-dimensionally.

The increase in the external efficiency of coupling out radiation is based on breaking the right-angled geometry of the thin-film semiconductor component by patterning the semiconductor thin film itself. The increase in efficiency is verified with the aid of simulations in the context of the detailed description below.

Preferably, the region of the multilayer structure that adjoins the second main area of the multilayer structure has convex elevations in the form of truncated pyramids, truncated cones, cones or sphere segments (two-dimensional patterning) or with a trapezoidal, triangular or circle segment cross-sectional form (one-dimensional patterning).

In a preferred exemplary embodiment, the aperture angle of the elevations lies between approximately 30° and

approximately 70°, particularly preferably between approximately 40° and approximately 50°. Moreover, the height of the elevations is at least as large, preferably approximately twice as large, as the height of a plane region of the multilayer structure between the active, radiation-generating layer and the elevations. The grid dimension of the elevations is chosen to be at most approximately five times, preferably at most approximately three times, as large as the height of the elevations.

The layer or interface coupled to the first main area of the multilayer structure advantageously has a degree of reflection of at least 70%, and better of at least 85%.

The multilayer structure may be applied either by its first main area directly or via a reflective layer on a carrier substrate, the reflective layer or the carrier substrate also serving as a contact area of the semiconductor component.

As compensation of a limited transverse conductivity of the thin semiconductor layer, a conductive, transparent layer may be applied on the second main area of the multilayer structure.

In order to afford protection against external influences, a transparent protective or antireflection layer may be applied on the second main area of the multilayer structure.

In accordance with a second aspect of the present invention, said object is achieved by means of a semiconductor component having the features of patent claim 18. Advantageous refinements and developments of this semiconductor component are defined in the dependent claims 19 to 32.

This radiation-emitting thin-film semiconductor component according to the invention likewise has a multilayer structure based on GaN, which contains an active, radiation-generating layer and has a first main area and a second main area - remote from the first main area - for coupling out the radiation generated in the active, radiation-generating layer. The first main area of the multilayer structure is once again coupled to a reflective layer or interface. In contrast to the semiconductor component described above, here a transparent layer is provided between the first main area of the multilayer structure and the reflective layer or interface, said transparent layer being patterned one- or two-dimensionally.

The patterning of this transparent layer between the multilayer structure and the reflective layer or interface has the same effect as the patterning of the multilayer structure itself and increases the external efficiency of coupling out radiation in the same way.

The transparent layer is preferably conductive in order to compensate for the limited transverse conductivity of a thin multilayer structure.

The transparent layer between the first main area of the multilayer structure and the reflective layer or interface has convex elevations preferably in the form of truncated pyramids or truncated cones (two-dimensional patterning) or a trapezoidal cross-sectional form (one-dimensional patterning).

In a preferred embodiment, said elevations have an aperture angle of between approximately 30° and approximately 70°, preferably between approximately 40° and approximately 50°. In this case, the height of the elevations is chosen to be at least as large, preferably approximately twice as large, as the height of a plane region of the multilayer structure between

the active, radiation-generating layer and the elevations, and the grid dimension of the elevations is at most five times, preferably at most three times, the height of the elevations.

The layer or interface coupled to the first main area of the multilayer structure preferably has a degree of reflection of at least 70%, particularly preferably of at least 85%.

The reflective layer may be applied on a carrier substrate or the reflective interface is formed by a carrier substrate, the reflective layer or the carrier substrate also serving as a contact area of the semiconductor component.

The above and further features and advantages of the present invention are described in more detail on the basis of the following detailed description of various preferred exemplary embodiments with reference to the accompanying drawings, in which:

Figure 1 shows a schematic illustration of a first exemplary embodiment of a semiconductor component according to the present invention in section;

Figures 2A to 2C show schematic illustrations for elucidating the optimum aperture angle of the elevations of the semiconductor component from Figure 1;

Figures 3A to 3E show results of various simulations for elucidating various optimal parameters of the elevations of the semiconductor component from Figure 1;

Figure 4 shows a schematic illustration of a modification of the first exemplary embodiment from Figure 1;

Figure 5 shows a schematic illustration of a second exemplary embodiment of a semiconductor component according to the present invention in section;

Figure 6 shows a schematic illustration of a further modification of the first exemplary embodiment from Figure 1;

Figure 7 shows a schematic illustration of yet another modification of the first exemplary embodiment from Figure 1; and

Figure 8 shows a highly diagrammatic illustration with regard to coupling out radiation from conventional semiconductor components.

Figure 1 illustrates a first preferred exemplary embodiment of a thin-film semiconductor component according to the present invention. A main constituent part of the semiconductor component 10 is a multilayer structure 12 based on GaN, which contains an active, radiation-generating layer 14. The multilayer structure 12 is grown epitaxially in a customary manner and contains, in a known manner, a plurality of GaN-based layers.

The multilayer structure 12 has a first main area 16 and a second main area 18 remote from the first main area, the radiation generated in the active, radiation-generating layer 14 finally being coupled out of the semiconductor component 10 through the second main area 18. In the exemplary embodiment shown, the active layer 14 is positioned nearer to the first main area 16 than to the second main area 18 of the multilayer structure

12. However, the present invention is in no way restricted to this. Rather, the active layer 14 may also be formed centrally in the multilayer structure 12 or nearer to the second main area 18. The position chosen in figure 1 is advantageous, however, for the patterning of the multilayer structure that is in accordance with the invention and is described below, since a thicker portion of the multilayer structure 12 is available for the patterning.

The multilayer structure 12 is applied via a reflective layer 28, preferably comprising an electrically conductive material, on a carrier substrate 30 made, for example, of sapphire, Si or SiC. The reflective layer 28 may be formed for example as a metallic contact area made of Ag, Al or an Ag or Al alloy or alternatively as dielectric mirror-coating comprising a plurality of dielectric layers. In an alternative embodiment, the multilayer structure 12 may also be applied directly on the carrier substrate 30, in this case the material of the carrier substrate 30 being selected in such a way that the interface between multilayer structure 12 and carrier substrate 30 is reflective.

As is clearly discernable in Figure 1, the region of the multilayer structure 12 above the active layer 14 can be subdivided essentially into a plane region 20 adjoining the active layer 14 and a patterned region 22 adjoining the second main area 18. The multilayer structure 12 is patterned for example by means of customary lithography and/or etching methods at the epitaxially grown semiconductor layers, by means of which groovelike recesses or depressions 24 are formed, between which corresponding elevations 26 remain.

The patterning of the multilayer structure 12 may be formed either one-dimensionally, that is to say with depressions 24 in only one coordinate direction of the

plane of the second main area 18, or two-dimensionally, that is to say with depressions 24 in two coordinate directions - preferably running perpendicular to one another - of the plane of the second main area 18. The elevations 26 produced between the depressions 24 are usually shaped in convex fashion. In this case, one-dimensional patternings are formed by way of example with a trapezoidal (see figure 1), triangular, circle segment or hemispherical cross-sectional form and two-dimensional patternings are correspondingly formed in the form of truncated pyramids, truncated cones, cones, sphere segments or hemispheres.

The elevations 26 in the form of truncated pyramids illustrated in Figure 1 have an aperture angle α, the definition of which can also be applied correspondingly to the other forms of the elevations 26 mentioned. On account of the convexly shaped elevations 26, the radiation generated in the active layer 14 is possibly reflected multiply at the interfaces of the multilayer structure 12 until the radiation finally impinges, in the radiation coupling-out cone dependent on the refractive indices of the materials and the surroundings, on the second main area 18 or the bottom of the depressions 24 and can thus couple out.

As illustrated in Figures 2A to 2C, the efficiency of coupling out radiation depends on the aperture angle α of the elevations 26. Very steep sidewalls, as in Figure 2A, increase the surface area of the device and are thus expedient for coupling out radiation, but a reduction of the number of modes that cannot be coupled out on account of total reflection is not obtained in this case. Likewise, the sidewalls of the elevations 26 should not be chosen to be too shallow, as illustrated in Figure 2C), since in this case the deviation from the plane-parallel plate is only small and a large number of multiple reflections have to be effected

before coupling out, which is negative on account of the unavoidable attenuation in this case.

A medium angular range of the aperture angle α of the elevations 26 as illustrated in Figure 2B is the most expedient. With this choice of the aperture angle α, the radiation that undergoes total reflection from one facet of the elevation 26 can be coupled out within the radiation coupling-out cone upon impinging on the next facet of the elevation 26, thereby keeping down the number of multiple reflections in the multilayer structure.

This estimation is also confirmed by a simulation, the result of which is shown in Figure 3A. In this case, the aperture angle α of the elevations 26 in truncated pyramid form is plotted on the abscissa, and the external efficiency of coupling out radiation is plotted on the ordinate. It is clearly evident that the best efficiency is achieved in a range of the aperture angle α between approximately 30° and approximately 70°, more precisely between approximately 40° and approximately 50°. The efficiency of coupling out radiation falls significantly for values of the aperture angle α above 70° and below 30°. An aperture angle α in the range around approximately 45° is thus preferable.

A further parameter that influences the external efficiency of coupling out radiation is the height h1 of the elevations 26. In order to obtain a high efficiency, the height h1 of the elevations 26 should be chosen to be at least as large as the height h2 of the plane region 20 adjoining the active layer 14. Preferably, the elevations 26 are formed twice as high as the plane region 20. A further increase in the height of the elevations 26 does not yield a further increase in the coupling out of radiation.

This is confirmed by a simulation illustrated in Figure 3B. The simulation result shows, for a plane region 20 having a height h2 of approximately 2 μm, the external efficiency of coupling out radiation against the height h1 of the elevations 26. At a height h1 of the elevations 26 below 2 μm, i.e. smaller than the height h2 of the plane region 20, radiation is coupled out only inadequately, while a significant increase in the efficiency is no longer discernable at heights h1 of the elevations 26 greater than approximately 4 μm.

Furthermore, elevations 26 having relatively small lateral dimensions are also preferable. As shown by the simulation result of Figure 3C, a grid dimension d of the elevations of at most approximately four to five times the height h1 of the elevations 26, preferably only of approximately one to three times the height h1 of the elevations, is advantageous for a good efficiency.

Since the concept of the thin-film semiconductor components is also based on multiple reflections, inter alia, the reflectivity of the rear side of the device, that is to say of the reflective layer 28 or of the reflective interface, likewise influences the external efficiency of the semiconductor component. It is evident in the diagram of Figure 3D that, in the case of a conventional planar thin film, the efficiency of coupling out radiation depends only to a small extent on the reflectivity of the rear-side contact area (lower curve in Figure 3D. For a patterned multilayer structure 12 as in Figure 1, however, the efficiency greatly depends on the reflectivity of the reflective layer 28 or interface (upper curve in Figure 3D) and should be chosen as far as possible to be above 70%, preferably above 85%.

Figure 4 illustrates a modification of the semiconductor component from Figure 1. The difference

between the two embodiments is that a protective or antireflection layer 32 is provided on the patterned second main area 18 of the multilayer structure 12. Said protective layer 32 is intended to protect the semiconductor from external influences, on the one hand, and the protective layer 32 may, on the other hand, act as an antireflective coating given a suitable choice of refractive index and thickness.

As a further variant of the first exemplary embodiment of the semiconductor component, a transparent, conductive layer with the lowest possible contact resistance with respect to the semiconductor may be provided on the patterned second main area 18 of the multilayer structure 12. Such a transparent, conductive layer makes it possible to compensate for the disadvantage that the patterning of the multilayer structure for increasing the efficiency of coupling out radiation at the same time reduces its transverse conductivity. An optimum current supply to all regions of the semiconductor component is obtained without impairing the coupling-out of radiation from the multilayer structure by metal contacts on the latter.

The transparent, conductive layer comprises, by way of example, ZnO, SnO, InO, CdO, GaO or a combination thereof. These materials exhibit an n-type or p-type conductivity and can be deposited by means of sputtering methods, CVD methods or vapor deposition.

A second exemplary embodiment of a radiation-emitting semiconductor component according to the invention is illustrated in figure 5.

The thin-film semiconductor component 10 has a multilayer structure 12 based on GaN with an active, radiation-generating layer 14. In contrast to the first exemplary embodiment described above, however, the second main area 18 of the multilayer structure 12,

through which the radiation generated in the active layer 14 is finally coupled out, is not patterned here. Rather a transparent layer 34 is provided between the first main area 16 and the reflective layer or interface on the carrier substrate 30, said transparent layer being patterned in order to increase the coupling out of radiation. This construction is preferable particularly when the metals that make good contact with the semiconductor 12 are not particularly highly reflective and, therefore, metals that reflect better, such as Ag, are intended to be used, which may contaminate the semiconductor on account of high migration.

In order to compensate for a lower transverse conductivity of the thin-film semiconductor, it is advantageous for the transparent layer 34 to be formed from a conductive material.

The patterning essentially corresponds to that described above on the basis of the first exemplary embodiment. However, the convex elevations 26′ that are appropriate here are primarily those in the form of truncated pyramids or truncated cones or those with a trapezoidal cross-sectional form. The patterning parameters explained above with reference to figure 3 can be applied to the elevations 26′ of this second exemplary embodiment. In this case, the plane layer 35 between the active layer 14 of the multilayer structure 12 and the transparent layer 34 is to be used as reference variable.

A further alternative embodiment of the semiconductor component of figure 1 is shown in figure 6. In the case of this semiconductor component 10, the multilayer structure 12 itself is not patterned. Rather an anti-reflection layer 32 applied on the second main area 18 of the multilayer structure 12 is provided with corresponding convex elevations 36.

Typical antireflection layers 32, for example made of SiO_2 or SiN_x, have a refractive index of less than 2, with the result that the radiation partly undergoes total reflection at the interface between semiconductor 12 and antireflection layer 32. As shown in the diagram of Figure 3E, the effectiveness of the patterned antireflection layer 32 decreases significantly as the refractive index deviates increasingly from that of the semiconductor with 2.5. A patterned antireflection layer having a low refractive index may nevertheless be advantageous, however, since even a wave subjected to total reflection penetrates the material having a lower refractive index approximately to a depth of half the wavelength, although it decays exponentially in this case. The height of the patterned antireflection layer should therefore be no more than a few 100 nm and the lateral dimensions are in the micrometers range.

If the lateral dimensions of the structures 36 of the antireflection layer 32 are reduced to the range of the wavelength of the radiation to be coupled out, an impinging wave is scattered at such a microstructure 36, as a result of which the beam is fanned out into a larger angular range.

Finally, Figure 7 shows a further modification of the semiconductor component from figure 1. A transparent, conductive layer 38 made, for example, of ZnO, SnO, InO, CdO, GaO or a combination thereof is applied on the multilayer structure 12, which is not patterned in this case. Said transparent, conductive layer 38 is patterned analogously to the first exemplary embodiment from figure 1, figure 7 illustrating a one-dimensional patterning with elevations with a trapezoidal cross-sectional form.

The contact resistance between the transparent, conductive layer 38 and the semiconductor 12 should be

as low as possible. If this is not the case, a metal layer (not illustrated) may be required between the layer 38 and the multilayer structure 12, said metal layer preferably being formed such that it is very thin and thus semitransparent or interrupted.